Influence of Plant Structure, Orifice Size, and Nozzle Inclination on Spray Penetration into Peanut Canopy

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Published in Transactions of the ASAE Vol. 45(5): 1295-1301 (2002 American Society of Agricultural Engineers).

Article was submitted for review in March 2002; approved for publication by the Power & Machinery Division of ASAE in August 2002.

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Abstract. *Three spray penetration tests were conducted 48, 68, and 109 days after peanuts were planted on single-row and twin-row beds. Spray was applied with flat fan pattern nozzles 8001VS, 8003VS, and 8005VS at 276 kPa pressure. Leaf area index, foliage density, and plant height and width were measured for each test and correlated with spray deposits at the bottom and middle of peanut canopies. Tests to compare spray penetrations by adjusting spray inclination from vertical to 15? toward travel direction were also conducted when peanut plants were 68 and 109 days old. Data showed that spray penetration into peanut canopies could be improved by increasing nozzle size from 8001VS to 8003VS but could not be improved by increasing the nozzle size from 8003VS to 8005VS after plants were 68 days old. Spray deposits on the top of canopies from the 8003VS nozzle were 10.5 times higher than at the middle position and 62 times higher than at the bottom positions when plants were 109 days old. The average spray deposits at the middle of canopies from the 8003VS nozzle were 1.251, 0.721 and 0.552 ? L/cm* ^{2} *when plants were 48, 68, and 109 days old, respectively. Spray deposits at the bottom and* *middle of peanut canopies tended to decrease linearly as the plant structure indicator of growth (square root of the product of plant height, width, leaf area index, and foliage density) increased. Inclining nozzles to discharge sprays from vertical to 15? toward travel direction did not significantly improve spray penetration.*

Keywords. Pesticides, Nozzles, Spray deposit, Peanut, Canopy penetration.

Annual pesticide expenditures for all farm uses increased from 6.3 billion to 8.8 billion U.S. dollars from 1991 to 1997 (USDA-ERS, 1998). The increase, in quantity of pesticide used, was mostly for fungicides and other pesticide products applied to high-value crops. The 23 million kilograms of fungicides estimated in 1997 was up 7% from 1996 and up 82% from 1990. During the last several decades, chemical application methods and equipment have been improved considerably to increase application accuracy. Still, in many cases, inefficient operation caused excessive or insufficient amounts of ingredients to reach target areas (Salyani and Cromwell, 1992; Smith, 1992; Fox et al., 1993; Zhu et al., 1997, Derksen et al., 2001). Spray performances are mostly affected by sprayer operation conditions, weather conditions (Smith et al., 1982), and target structures (Walklate et al., 2000). Due to increasing concern about pest control costs and environmental pollution, it is essential to apply pesticides with precision and care.

Peanut (*Arachis hypogaea* L.) is one of the major cash crops in the southeastern U.S. Insecticides and fungicides have traditionally been applied to peanuts 5 to 8 times per year as foliar sprays on a 10- to 14-day treatment interval schedule beginning 30 to 60 days after planting (DAP) and ending 14 to 21 days before digging. With such an intensive spray application program, costs to control peanut insects and diseases are a major production expense.

To determine the effectiveness of chemicals, many field tests have been conducted with different combinations of fungicides to control soilborne (Csinos, 1987; Hagan et al., 1991; Damicone and Jackson, 1996; Besler et al., 2001) and foliar (Johnson et al., 1985) peanut diseases. However, methods to apply chemicals to the peanut canopy could significantly influence the effectiveness of fungicides for leaf spot disease control (Sumner et al., 2000). Brenneman et al. (1990) used surface-stripping of leaf discs with toluene to determine deposition and retention of chlorothalonil on peanut foliage and found the effectiveness of chlorothalonil decreased nearly to zero in 14 days after application.

Hydraulic fan pattern nozzles are typically used to discharge insecticides and fungicides to peanut canopies. Improper operation with fan pattern nozzles results in excessive application of insecticide and fungicide to peanut plants, which leads to greater cost and contamination of the environment, soil, and groundwater (Ozkan, 1987; Wolak, 1989). Conversely, improper operation may not deliver sufficient amounts of fungicide to the bottom of the canopy, where fungi normally attack. The structure of peanut plants changes dramatically and the foliage increases four to five fold between 40 and 100 DAP. However, pest management guidelines provide little information that is helpful to peanut growers in selecting appropriate pesticide delivery methods because recommendations are for constant rates applied over the whole growing season. Growers use the same nozzles throughout the growing season. When plants grow larger, growers tend to increase the operating pressure of pesticide delivery systems in the hope of increasing canopy penetration and spray coverage on the undersides of leaves. This can produce a significant amount of drift that may not provide the intended biological impact. There has been very little research to enhance the placement and efficacy of insecticides and fungicides using fan pattern nozzles for different size canopies during the peanut growing season.

The objectives of this research were to determine the amount of sprays reaching the bottom, middle, and top of peanut canopies at different growing stages and to determine the influence of nozzle orifice size, spray inclination, peanut canopy size, leaf area index, and foliage density on spray penetration.

Material and Methods

Three spray penetration tests for peanut canopies were conducted at three different growing stages during crop year 2001. The cultivar Georgia Green was planted with 20 seeds/m in Greenville type soil on 25 May 2001. Nine randomly selected plants from both a single-row bed and a twin-row bed (fig. 1) were used for all three tests. Plant spacing between two rows on the twin-row bed was 23 cm. To protect plants from foliar diseases, ground spray applications of fungicides were made every two weeks for a total of seven applications during the growing season.

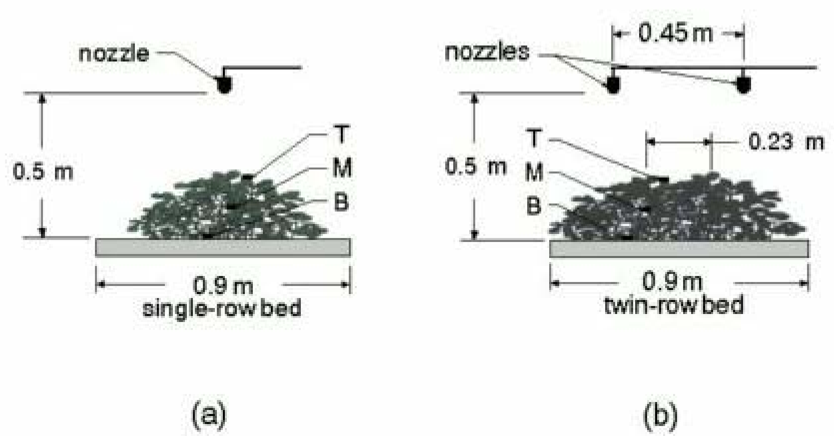

Figure 1. Spray penetration test for peanut plants of three ages: (a) setup for plants on single-row bed, and (b) setup for plants on twin-row bed. T, M, and B represent spray sample positions at the top, middle, and bottom of canopies, respectively.

The first test was conducted between 9:30 and 10:30 a.m. on 12 July (48 DAP). The average canopy size was 0.34 m in width and 0.17 m in height for single-row plants and 0.70 m in width and 0.18 m in height for twin-row plants. Before this test, the plants had been treated with fungicides twice. The gusts were mostly from east to west with average velocity of 2 m/s during the test. The row direction was also from east to west. Average ambient temperature and relative humidity during the test were 30?C and 71%, respectively. Wind velocity was measured with a Model 490 mini-anemometer (Kurz Instruments, Inc., Monterey, Cal.). The wind velocity probe was set at 0.5 m above the bed. Ambient temperature and relative humidity were measured with a Model 3309-60 handheld thermo-hygrometer (Cole-Parmer Instrument Company, Chicago, Ill.).

The second test was conducted between 10:00 and 11:30 a.m. on 1 August (68 DAP). The average canopy size was 0.67 m in width and 0.26 m in height for single-row plants and 0.82 m in width and 0.26 m in height for twin-row plants. The gusts were mostly from east to west with average velocity of 2.5 m/s during the test. Average ambient temperature and relative humidity during the test were 31?C and 66%, respectively.

The third test was conducted between 9:30 and 11:30 a.m. on 11 September (109 DAP). The average canopy size was 0.95 m in width and 0.37 m in height for single-row plants and 0.98 m in width and 0.37 m in height for twin-row plants. The gusts were mostly from east to west with average velocity of 2.0 m/s during the test. Average ambient temperature and relative humidity during the test were 27?C and 78%, respectively.

Three different size, TeeJet flat fan pattern nozzles (8001VS, 8003VS, and 8005VS, Spraying Systems Co., Wheaton, Ill.) were used at 276 kPa operating pressure. The nominal flow rate at 276 kPa was 0.39, 1.16, and 1.94 L/min for 8001VS, 8003VS, and 8005VS, respectively. Each size nozzle treated three different plants on each single-row bed and twin-row bed as spray targets. The sprayer was traveling at 6.4 km/hr from west to east during the tests.

For plants on the single-row bed, one nozzle was mounted 0.5 m above the soil surface and directly over the plant row (fig. 1a). For plants on the twin-row bed, two nozzles of the same size were used to discharge droplets to cover all plants in the twin rows. The nozzles were mounted 0.5 m above the soil surface and spaced 0.45 m apart (fig. 1b). The centerline between the two nozzles was centered over the middle line of the twin rows.

For the first test, nozzles were mounted on the spray boom to discharge droplets vertically toward the ground. For the second and third tests, spray was again discharged vertically as well as 15? inclined from vertical toward the direction of tractor travel direction. The test with 15? nozzle inclination started one hour after spray samples were collected from the previous test in which sprays were discharged vertically toward the ground. Tests with two nozzle angles used the same plants and same sample locations.

Petri dishes, 35 mm in diameter and 10 mm in depth, were placed at the top, middle, and bottom positions in each canopy (figs. 1a and 1b) to collect spray samples. Dishes were collected 15 minutes after spraying and stored in 125 mL wide-mouth glass bottles. Petri dishes for the bottom sample were placed on the soil surface for each of the three tests. Positions of the middle and top petri dishes were adjusted according to the plant height. The petri dishes at the top and middle positions were supported with vertical ring holders, which could be adjusted vertically and radially on 1 cm diameter metal bars. The metal bars were permanently installed 15 cm away from the center of each individual plant for the entire season. All spray samples were stored in a refrigerator and analyzed within 24 hours after they were collected.

The spray mixture contained water and Acid Yellow 7 (Carolina Color and Chemical Co., Charlotte, N.C.) at a concentration of 3.38 ?g/?L (see eq. 1) for all tests. Spray deposits in petri dishes were dissolved in 40 mL of purified water (prepared with 4-bowl Milli-Q Water System, Model ZD20, Millipore Corporation, Bedford, Mass.) and filtered through Whatman No. 4 filter paper. Indivi dual filtrates were transferred to 1 mL vials and placed in a Model 717 plus autosampler (Waters Corporation, Milford, Mass.). The concentration of each sample was determined by injecting 200 ?L into a liquid chromatography (LC) system consisting of a Mode l 515 LC pump (Waters Corporation, Milford, Mass.) and a Model RF-551 fluorescence detector (Shimadzu Corporation, Kyoto, Japan) with excitation and emission wavelengths of 430 and 500 nm, respectively. The mobile phase consisted of water-isopropanol (80:20, v/v) at a flow rate of 0.4 mL/min. The system did not contain a chromatographic column, but samples were injected into the flow moving directly to the detector. Chromatograms were produced with the Class VP Chromatography Data System, version 4.2 (Shima dzu Corporation, Kyoto, Japan). Separate calibration curves, based on peak height, were prepared for each test date by injecting a series of standards containing 0.5 to 3.0 ?g of Acid Yellow 7 per mL of water. If a sample concentration fell outside the lin ear range of the calibration curve, then it was diluted and reinjected.

The volume (in ?L/cm^2) of spray deposited in petri dishes was calculated from the following formula:

Spray deposit = [(C □ 40)/3.38]/9.62 (1)

where

C = concentration of Acid Yellow 7 in each sample collected (?g/mL)

40 = volume of water used to dissolve spray deposits (mL)

3.38 = concentration of Acid Yellow 7 applied as spray (?g/?L)

9.62 = surface area of the petri dish (cm^2).

Leaf area index (LAI) and foliage density for each of the 18 peanut canopies were measured using an LAI-2000 plant canopy analyzer (Li-Cor, Inc., Lincoln, Nebraska). Measurements were taken just prior to the first spray test and one day prior to the second and third spray tests. For LAI, the instrument recorded the attenuation of diffuse sky radiation at five angles simultaneously as it passed through the canopy and gave an estimate of the foliage amount in that canopy per unit ground area. Foliage density (foliage area divided by canopy volume) for individual plants was measured by taking the mean path lengths for each of the five zenith rings of the instrument and changing the DISTS vectors in the meter accordingly. Three measurements of foliage density were taken for each plant: one on the east side, center, and west side of each plant. Both LAI and foliage density were taken under artificial shade.

Data were analyzed by one-way ANOVA, and differences among means were determined with the Student-Newman-Keuls test using Sigma Stat version 1.0 (Jandel Scientific, San Rafael, Cal.). A t-test with the paired experiments was used to analyze for differences between two nozzle inclinations. All significant differences were determined at the 0.05 level of significance.

Results and Discussion

Nozzle Inclination and Planting Method

There were no significant differences between deposits produced by nozzles vertically toward the ground and inclined 15? from vertical toward travel direction. This result was true for both 68 and 109 DAP canopies on single- and twin-row beds and all three nozzle sizes operated at 276 kPa and 6.4 km/hr travel speed. The average spray deposits at the bottom, middle, and top of canopies from the three nozzles discharging sprays vertically toward the ground are shown in tables 1, 2, and 3, respectively.

Statistical analysis also indicated no significant differences for deposits between single- and twin-row planting methods when one nozzle was mounted above the single-row plants and two nozzles with 0.45 m spacing were mounted above twin-row plants. This result was true for 48, 68, and 109 DAP canopies, both nozzle angles, and all three nozzle sizes operated at 276 kPa and 6.4 km/hr travel speed.

Nozzle Orifice Size

Tables 1, 2, and 3 show the average spray deposits discharged from three nozzles for samples collected at the bottom, middle, and top positions, respectively, in peanut canopies at three growing stages. Each value of spray deposits in the tables represents the mean deposit of single- and twin-row canopies with three replications.

The nominal flow rate of the 8001VS nozzle at 276 kPa was 3 times lower than the 8003VS nozzle and 5 times lower than the 8005VS nozzle, demonstrating a linear relationship among the nozzles for output. However, data in tables 1 and 2 illustrate that this relationship was not reflected in amount of spray reaching the bottom and middle of canopies, especially after plants became larger. Spray deposits at the bottom and middle positions of peanut canopies significantly increased as nozzle orifice size increased when plants were 48 DAP. The 8003VS and 8005VS nozzles produced 2.1 and 3.5 times higher deposits at the bottom and 2.9 and 7.4 times higher deposits at the middle of canopies than the 8001VS nozzle when plants were 48 DAP. However, differences in spray deposits for the 8003VS and 8005VS nozzles at the bottom and middle of canopies at 68 and 109 DAP were not significant, while the 8001VS nozzle still deposited significantly less spray. At the top of canopies, significant differences among the three nozzles were seen at all times (tables 1, 2, and 3). Both the 8003VS and 8005VS nozzles produced substantially higher spray deposits at the bottom, middle, and top of canopies than the 8001VS nozzle during the entire growing season. Therefore, the spray penetration into peanut canopies was improved by changing from the 8001VS nozzle to the 8003VS nozzle, but it was not improved by changing from the 8003VS nozzle to the 8005VS nozzle after plants were 68 DAP.

Table 1. Average spray deposits at the bottom of canopies at three growing ages on single-row and twin-row beds for 8001VS, 8003VS, and 8005VS flat fan pattern nozzles operated vertically toward the ground at 276 kPa pressure and 6.4 km/hr travel speed.

Nozzle	Days after Planting							
	48			68			109	
	Deposit (? L/cm ^{2})	CV [a]		Deposit (? L/cm ^{2})	CV		Deposit (? L/cm ^{2})	CV
8001VS	0.399Aa [b]	0.31		0.059Ab	0.52		0.040Ab	0.53
8003VS	0.818Ba	0.26		0.165Bb	0.48		0.093Bb	0.68
8005VS	1.389Ca	0.48		0.181Bb	0.65		0.193Bb	0.97

[a] CV = coefficient of variation of the average spray deposit.

[b] Means in a column followed by different uppercase letters are significantly different ($p < 0.05$). Means in a row followed by different lowercase letters are significantly different ($p < 0.05$).

Table 2. Average spray deposits at the middle of canopies at three growing ages on single-row and twin-row beds for 8001VS, 8003VS, and 8005VS flat fan pattern nozzles operated vertically toward the ground at 276 kPa pressure and 6.4 km/hr travel speed.

Nozzle	Days after Planting							
	48			68			109	
	Deposit (? L/cm ^{2})	CV [a]		Deposit (? L/cm ^{2})	CV		Deposit (? L/cm ^{2})	CV
8001VS	0.423Aa [b]	0.35		0.261Aa	0.84		0.205Aa	0.50
8003VS	1.251Ba	0.32		0.721Bb	0.57		0.552ABb	0.69
8005VS	3.125Ca	0.38		1.061Bb	0.60		1.147Bb	0.74

[a] CV = coefficient of variation of the average spray deposit.

[b] Means in a column followed by different uppercase letters are significantly different (p <

0.05). Means in a row followed by different lowercase letters are significantly different ($p < 0.05$).

Table 3. Average spray deposits at the top of canopies at three growing ages on single-row and twin-row beds for 8001VS, 8003VS, and 8005VS flat fan pattern nozzles operated vertically toward the ground at 276 kPa pressure and 6.4 km/hr travel speed.

Nozzle	Days after Planting					
	48		68		109	
	Deposit (? L/cm ^{2})	CV [a]	Deposit (? L/cm ^{2})	CV	Deposit (? L/cm ^{2})	CV
8001VS	1.266Aa [b]	0.31	1.639Aa	0.32	3.487Ab	0.30
8003VS	3.085Ba	0.09	4.527Bab	0.24	5.775Bb	0.29
8005VS	5.673Ca	0.14	6.428Ca	0.25	7.181Ca	0.20

[a] CV = coefficient of variation of the average spray deposit.

[b] Means in a column followed by different uppercase letters are significantly different ($p < 0.05$). Means in a row followed by different lowercase letters are significantly different ($p < 0.05$).

Larger nozzles discharged a higher volume of spray that penetrated the dense canopy of peanut plants and provided higher spray deposits at the bottom, middle, and top parts of canopies, but variation in deposits in the lower part of canopies from larger nozzles for three replications was higher than from smaller nozzles. In most cases, the coefficient of variation of average spray deposits at the bottom and middle of canopies was higher with the 8005VS nozzle than with the 8003VS and 8001VS nozzles (tables 1 and 2). Therefore, the 8003VS and 8001VS nozzles produced less variation in spray coverage at the bottom and middle of canopies across the field than the 8005VS nozzle.

Plant Age and Sample Position

All three nozzles were able to discharge adequate spray to the bottom of canopies when plants were young. However, when plants grew larger, spray deposits at the bottom of canopies decreased dramatically. Data in table 1 show that the amount of deposits at the bottom of canopies decreased significantly as the plant age increased from 48 to 68 DAP for all three nozzles. For example, the spray deposits at the bottom of canopies from the 8003VS nozzle were 0.818 and 0.165 ?L/cm ^{2} when plant age was 48 and 68 DAP, respectively. However, there was no significant difference between 68 and 109 DAP for the spray deposits at the bottom of canopies.

In the middle of canopies, spray deposits from the 8001VS nozzle did not differ significantly among plant ages (table 2). However, there was a significant decrease in spray deposition between 48 and 68 DAP, but no significant difference between 68 and 109 DAP with the 8003VS and 8005VS nozzles. Therefore, to obtain sufficient coverage of chemicals at the bottom and middle of peanut canopies to control soilborne and other diseases, nozzle orifice size should be increased from the 8001VS nozzle to the 8003VS nozzle. Such a change of nozzle size would also take care of spray drift concerns. Spray penetration performance was not significantly improved by changing from the 8003VS nozzle to the 8005VS nozzle after plants became larger.

Spray deposits at the top of canopies at 48 DAP were significantly lower than at 109 DAP for the 8001VS and 8003VS nozzles, but this difference was not significant for the 8005VS nozzle (table 3). The top leaves of older plants were closer to the nozzles and were expected to receive more spray deposits than younger plants. Because of the high flow rate of the 8005VS nozzle, there was considerable spray runoff when droplets impacted the top of canopies.

Significant differences in spray deposition were usually found when comparing the top, middle, and bottom of canopies. The only exception was that no significant difference was seen between the bottom and middle positions for the 8001VS nozzle at 109 DAP. At 48 DAP, the spray deposits at the top of canopies were 2.5 and 3.8 times higher than at the middle and bottom of canopies, respectively, with the 8003VS nozzle (tables 1, 2, and 3). However, such differences increased dramatically when the plants grew older. At 109 DAP, the spray deposits on the top of canopies were 10.5 times higher than at the middle position and 62 times higher than at the bottom position when the 8003VS nozzle was used. Therefore, especially during the late growing stages, most of the spray mixture was deposited at the top of canopies.

Plant Structure

Twin-row plants were significantly wider than single-row plants, but there was no significant difference in height (table 4). The width of single-row plants tended to become closer to twin-row plants when they grew larger. The width of plants linearly increased with plant height. The linear regression equation for width and height was *width* = 2.64 *height* - 0.056 with $r^2 = 0.91$ for single-row plants, and *width* = 1.04 *height* + 0.48 with $r^2 = 0.93$ for twin-row plants. Changes in the canopy cross-sectional area, the product of height and width, for twin-row plants were smaller than for single-row plants during the entire growing season.

Table 4. Peanut plant height and width on single-row and twin-row beds at three different growing stages.

Planting Method	Mean Height (m)				Mean Width (m)		
	Days after Planting				Days after Planting		
	48	68	109		48	68	109
Single-row	0.17Aa [a]	0.26Ab	0.37Ac		0.34Aa	0.67Ab	0.95Ac
Twin-row	0.18Aa	0.26Ab	0.37Ac		0.70Ba	0.82Bb	0.98Bc

[a] Means in a column followed by different uppercase letters are significantly different ($p < 0.05$). Means in a row within sections (48, 68, 109) followed by different lowercase letters are significantly different ($p < 0.05$).

The influence of plant height on spray deposits at the bottom and middle of canopies with the three nozzles is shown in figures 2 and 3, respectively. Data shown in the figures are each individual spray deposit obtained from three tests at three plant ages with two planting methods. Spray deposits at the bottom and middle of canopies decreased as the plant height increased for all three nozzles. Taller plants developed a greater chance for the top part of canopies to intercept spray droplets, resulting in less spray deposits in the lower part of canopies. The 8005VS nozzle produced substantially higher average deposits at the bottom and middle of canopies than the other two nozzles, even when the plant height was greater than 0.4 m.

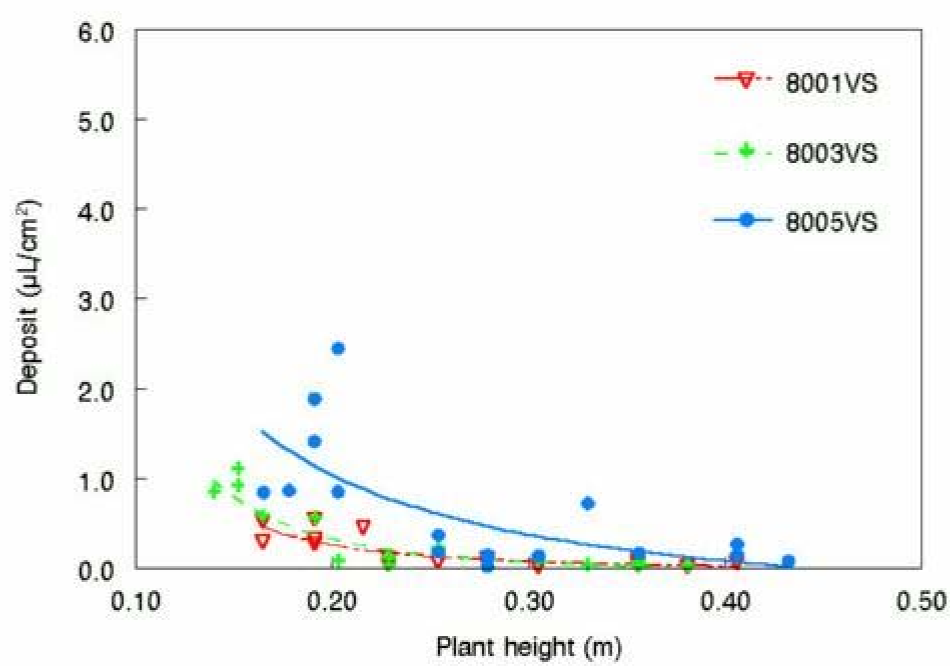

Figure 2. Effect of plant height on spray deposits at the bottom of canopies from 8001VS, 8003VS, and 8005VS flat fan pattern nozzles. Lines display the trend in spray deposit with plant height.

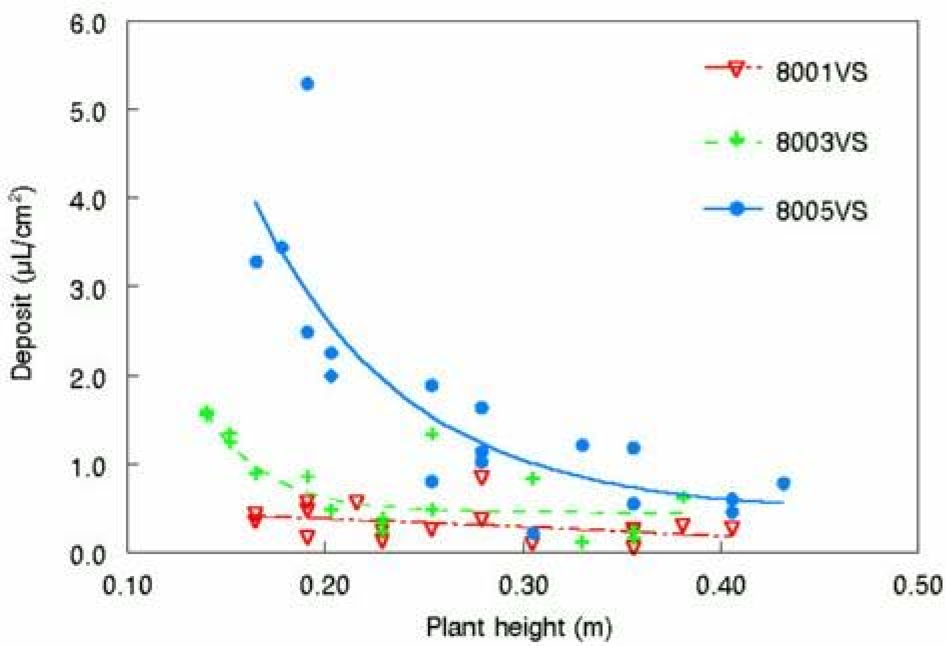

Figure 3. Effect of plant height on spray deposits in the middle of canopies from 8001VS, 8003VS, and 8005VS flat fan pattern nozzles. Lines display the trend in spray deposit with plant height.

Peanut plant structure varied greatly with plant growing stage. Data in table 5 indicate that the LAI increased significantly as the plant age increased for both planting methods, while the LAI of twin-row plants was always significantly larger than that of single-row plants. The average LAI increased from 1.29 to 4.13 for single-row plants and from 2.77 to 5.19 for twin-row plants when plant age increased from 48 to 109 days. Figures 4 and 5 show the influence of LAI on spray deposits at the bottom and middle of canopies, respectively. Spray deposits tended to decrease as LAI increased for all th ree nozzles. For example, at the bottom of canopies, the spray deposits from the 8003VS nozzle were 0.59 ?L/cm ^{2} when LAI was 1.59 and 0.08 ?L/cm ^{2} when LAI was 4.34. However, spray deposit values from the 8005VS nozzle fluctuated considerably when LAI changed.

Table 5. Mean leaf area index (LAI) of peanut plants on single-row and twin-row beds at three different growing stages.

Planting Method	Days after Planting							
	48			68			109	
	LAI	CV [a]		LAI	CV		LAI	CV
Single-row	1.29Aa [b]	0.26		2.95Ab	0.19		4.13Ac	0.09

Twin-row	2.77Ba	0.19		4.66Bb	0.12		5.19Bb	0.12

[a] CV = coefficient of variation of the average spray deposit.

[b] Means in a column followed by different uppercase letters are significantly different ($p < 0.05$). Means in a row followed by different lowercase letters are significantly different ($p < 0.05$).

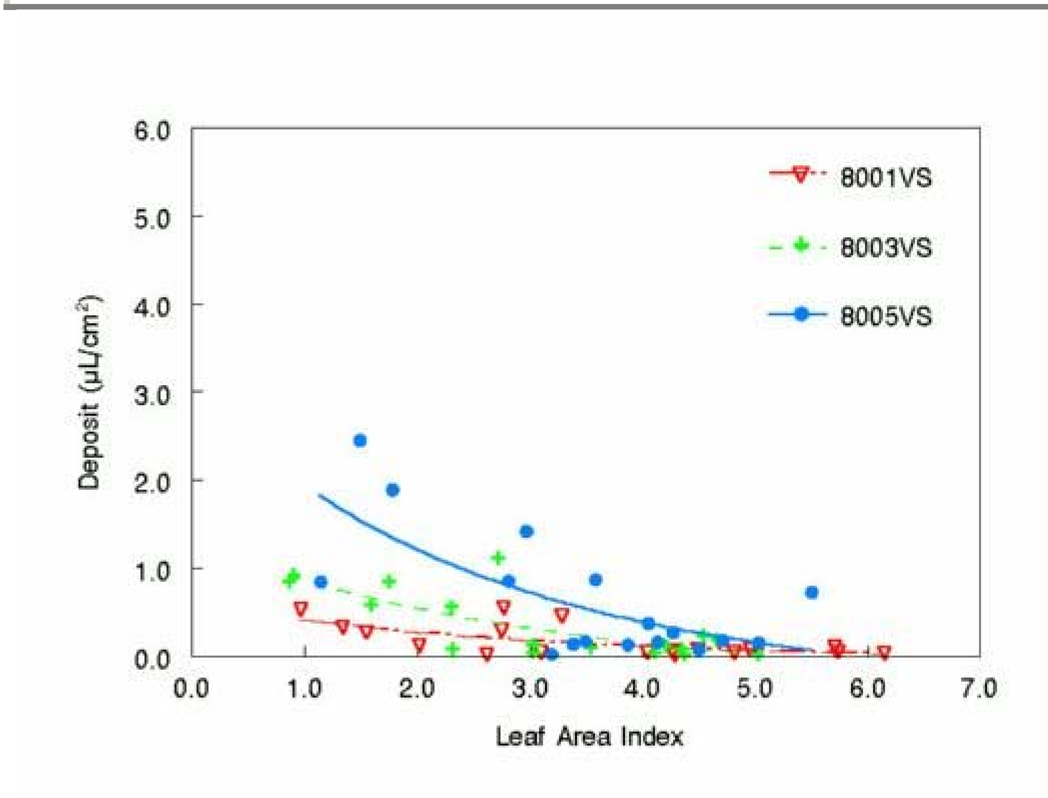

Figure 4. Effect of plant LAI on spray deposits at the bottom of canopies from 8001VS, 8003VS, and 8005VS flat fan pattern nozzles. Lines display the trend in spray deposit with plant LAI.

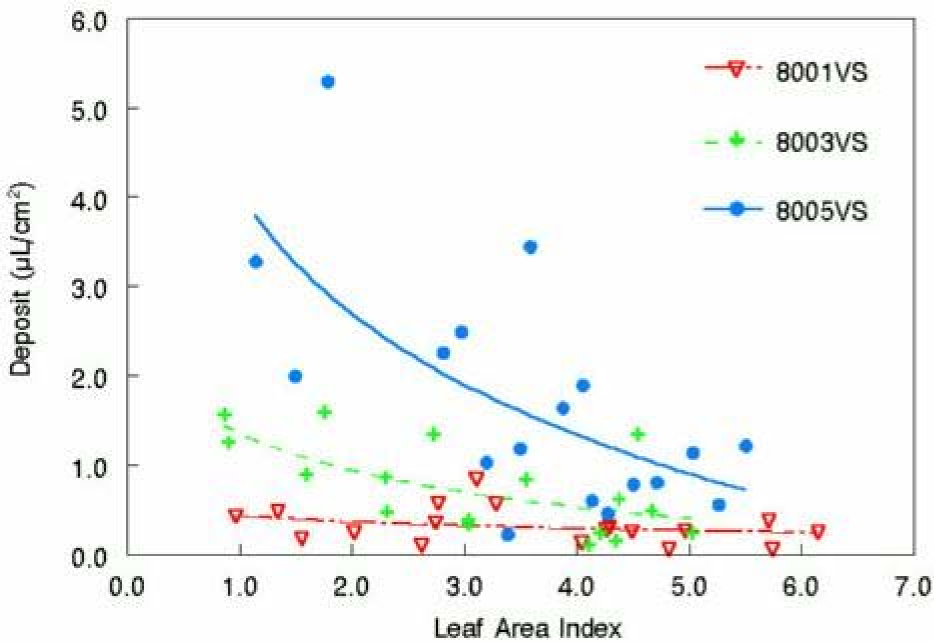

Figure 5. Effect of plant LAI on spray deposits in the middle of canopies from 8001VS, 8003VS, and 8005VS flat fan pattern nozzles. Lines display the trend in spray deposit with plant LAI.

Foliage density significantly increased and then decreased as plant age increased during the growing season (table 6). This was because the plant height and width grew faster than the leaves, which resulted in thinner canopies although the plant was taller than before. There was no significant difference in foliage density between single- and twin-row plants when plants were 48 and 68 DAP. The average foliage density for single- and twin-row plants was 23.4, 35.0, and 21.1 m^{-1} when plants were 48, 68, and 109 DAP, respectively. Figures 6 and 7 illustrate that spray deposits at the bottom and middle of canopies tended to decrease as foliage density increased. However, the scale of such decrease due to foliage density was much lower than plant height and LAI. During the later growing stage, spray deposits at the bottom and middle of peanut canopies were very low although the foliage density decreased. Therefore, the major influences of plant structure on spray deposits at the bottom and middle of peanut canopies were plant height and LAI. Foliage density had a very little influence on spray deposits.

Table 6. Mean foliage density (FD) of peanut plants on single-row and twin-row beds at three different growing stages.

Planting Method	Days after Planting							
	48			68			109	
	FD (m^{-1})	CV [a]		FD (m^{-1})	CV		FD (m^{-1})	CV

Single-row	24.5Aa [b]	0.22		33.2Ab	0.08		22.6Aa	0.15
Twin-row	22.3Aa	0.14		36.9Ab	0.14		19.5Bc	0.10

[a] CV = coefficient of variation of the average spray deposit.

[b] Means in a column followed by different uppercase letters are significantly different ($p < 0.05$). Means in a row followed by different lowercase letters are significantly different ($p < 0.05$).

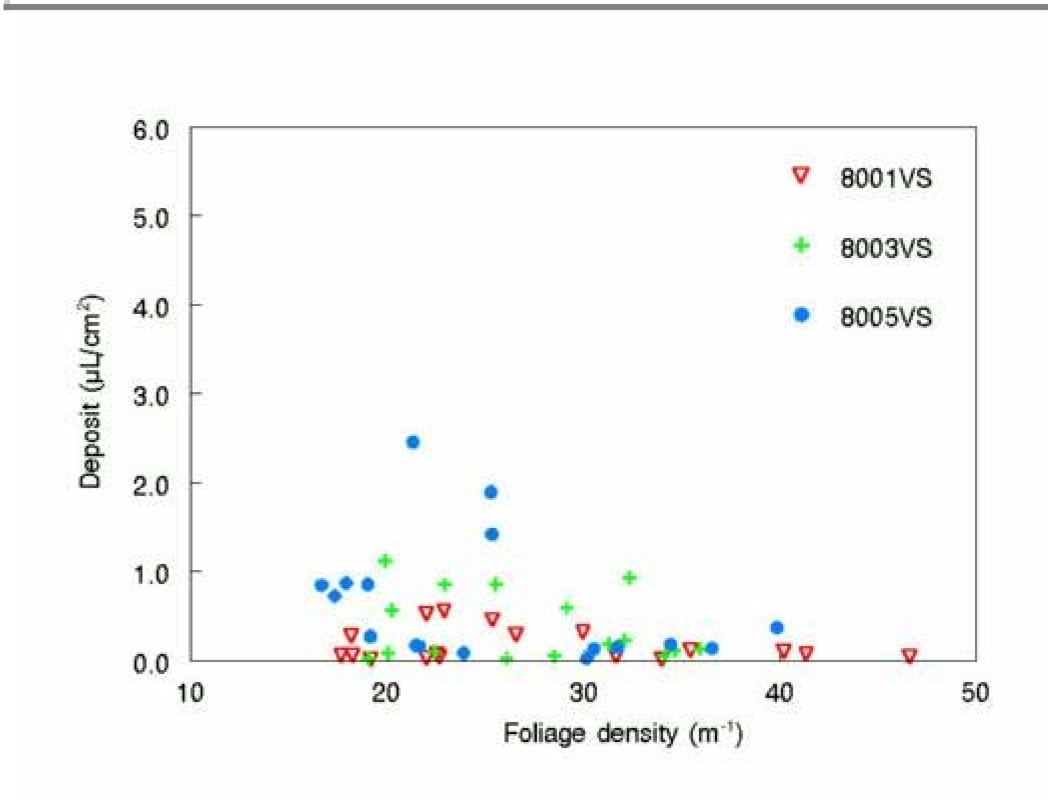

Figure 6. Effect of plant foliage density on spray deposits at the bottom of canopies from 8001VS, 8003VS, and 8005VS flat fan pattern nozzles.

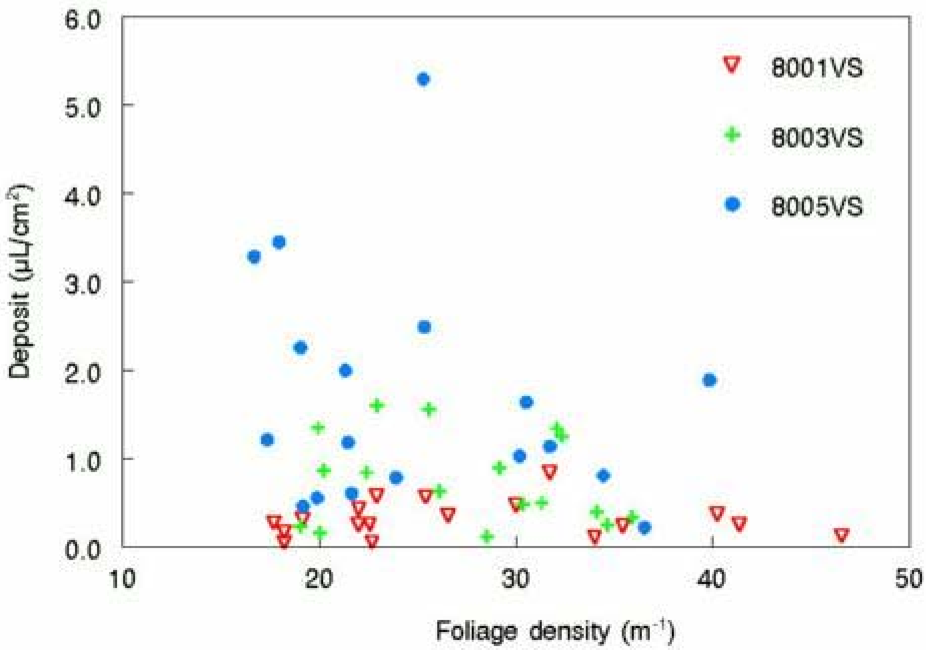

Figure 7. Effect of plant foliage density on spray deposits in the middle of canopies from 8001VS, 8003VS, and 8005VS flat fan pattern nozzles.

Spray deposits were more predictable when the plant height, width, LAI, and foliage density were combined into a plant structure indicator of growth. Linear relationships with r^2 between 0.69 and 0.85 were obtained for spray deposits at the bottom and middle of canopies as a function of the plant structure indicator of growth, which was the square root of the product of plant height, width, LAI, and foliage density for all three nozzles (figs. 8 and 9). The plant structure indicator varied with plant age. The average plant structure indicator for single- and twin-row plants was 2.09, 5.05, and 5.90 when plants were 48, 68, and 109 DAP, respectively. At these growing stages, when one 8003VS nozzle was used to spray single-row plants and two 8003VS nozzles were used to spray twin-row plants, the spray deposit at the bottom of canopies predicted from the equation shown in figure 8 was 0.667, 0.161, and 0.016 ?L/cm ^{2}, respectively. To obtain expected spray application accuracy and reduce the expense of disease control for peanuts, spray nozzles should be carefully selected according to the overall plant structure.

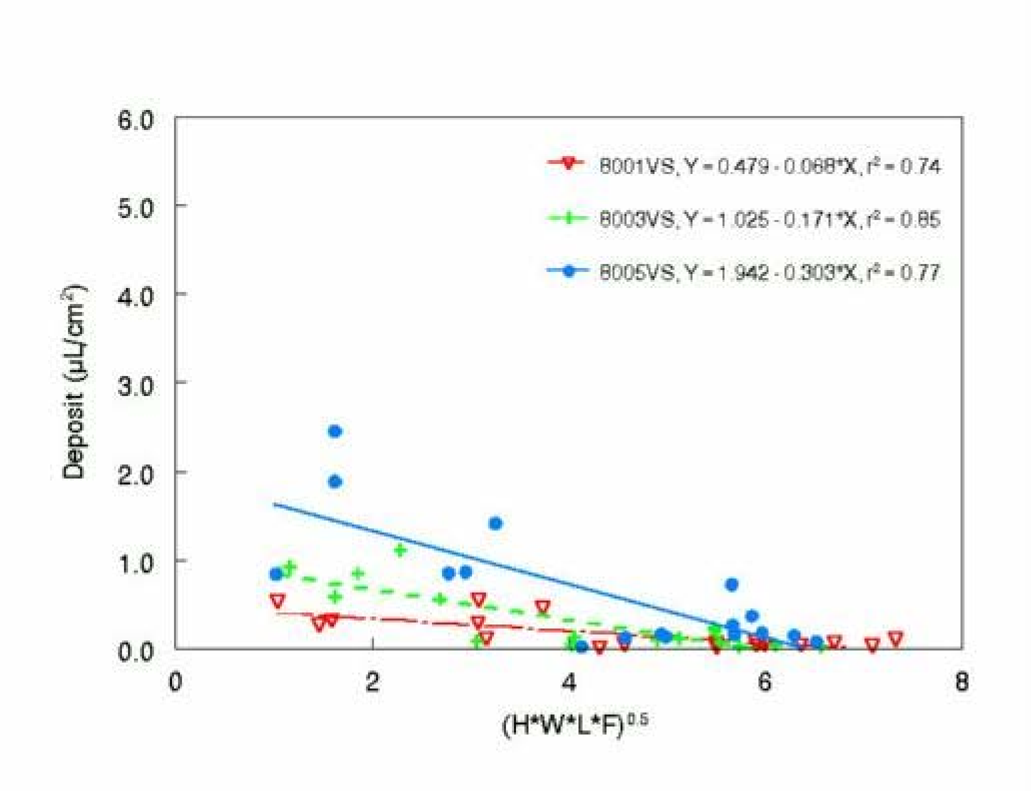

Figure 8. Effect of plant structure indicator of growth (square root of the product of plant height (H), width (W), leaf area index (L), and foliage density (F)) on spray deposits at the bottom of canopies from 8001VS, 8003VS, and 8005VS flat fan pattern nozzles.

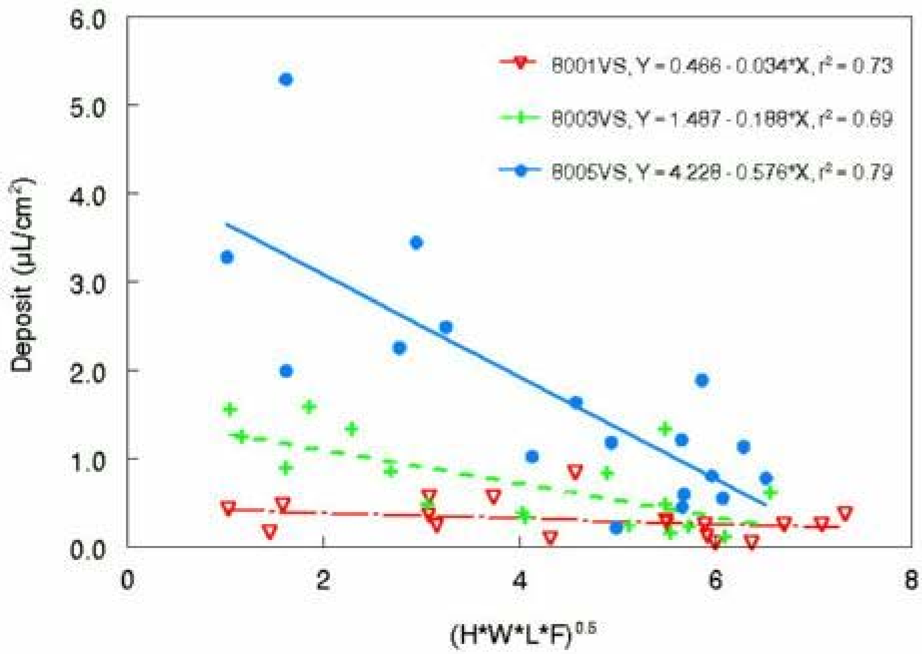

Figure 9. Effect of plant structure indicator of growth (square root of the product of plant height (H), width (W), leaf area index (L), and foliage density (F)) on spray deposits in the middle of canopies from 8001VS, 8003VS, and 8005VS flat fan pattern nozzles.

Summary and Conclusions

- Spray deposits at the bottom and middle positions of peanut canopies increased as nozzle orifice size increased at the early plant growing stage, but the increase was not significant when the canopies became larger. Changing nozzle size from the 8003VS nozzle to the 8005VS nozzle did not significantly improve the spray penetration into the bottom of canopies. About 0.093 ?L/cm ^{2} of spray mixture applied with the 8003VS nozzle operated at 276 kPa could reach the bottom of canopies when plants were 109 DAP.
- During the late growing stages, spray penetration through the top of the canopy was poor. With the 8003VS nozzle operated at 276 kPa and 6.4 km/hr, the average spray deposits on the top of peanut canopies on twin-row beds were 10.5 times higher than at the middle and 62 times higher than at the bottom of the canopies when the plants were 109 DAP.
- Spray deposits at the bottom and middle of peanut canopies linearly decreased as the plant structure indicator of growth (square root of the product of plant height, width, LAI, and foliage density) increased. Plant height and LAI had more influence on spray penetration into peanut canopies than foliage density.

- Paired experiment analysis showed there was no significant difference between spray deposits at the bottom and middle of canopies when spray inclination was adjusted from vertical to 15? toward travel direction. Further study should be conducted to determine the spray penetration performance in peanut canopies with more nozzle inclinations and operating pressures as well as travel speeds.
- There was no significant difference for spray deposits between single-row and twin-row planting methods when one nozzle was used to spray single-row plants and two nozzles were used to spray twin-row plants.

Acknowledgements

The authors thank Ernest Yoder for conducting spray penetration tests, Kathy Gray for measuring LAI and foliage density, and Milbra Schweikert for analyzing spray deposit samples.

REFERENCES

Besler, B. A., W. J., Grichar, O. D. Smith, and A. J. Jaks. 2001. Response of peanut cultivars to full and reduced spray programs of tebuconazole for control of southern stem rot. *Peanut Science* 28(1): 5-8.

Brenneman, T. B., H. R. Sumner, G. W. Harrison. 1990. Deposition and retention of chlorothalonil applied to peanut foliage: Effects of application methods, fungicide formulations, and oil additives. *Peanut Science* 17(2): 80-84.

Csinos, A. S. 1987. Control of southern stem rot and rhizoctonia limb rot of peanut with flutolanil. *Peanut Science* 14(2): 55-58.

Damicone, J. P., and K. E. Jackson. 1996. Disease and yield responses to fungicides among peanut cultivars differing in reaction to sclerotinia blight. *Peanut Science* 23(2): 81-85.

Derksen, R. C., S. A. Miller, H. E. Ozkan, and R. D. Fox. 2001. Spray deposition characteristics on tomatoes and disease management as influenced by droplet size, volume, and air-assistance. ASAE Paper No. 011120. St. Joseph, Mich.: ASAE.

Fox, R. D., D. L. Reichard, R. D. Brazee, C. R. Krause, and F. R. Hall. 1993. Downwind residues from spraying a semi-dwarf apple orchard. *Trans. ASAE* 36(2): 333-340.

Hagan, A. K., J. R. Weeks, and K. Bowen. 1991. Effects of application timing and method on control of southern stem rot of peanut with foliar-applied fungicides. *Peanut Science* 18(1): 47-50.

Johnson, C. S., P. M. Phipps, and M. K. Beute. 1985. Cercospora leafspot management decisions: An economic analysis of a weather-based strategy for timing fungicide applications. *Peanut Science* 12(2): 82-85.

Ozkan, H. E. 1987. Sprayer performance evaluation with microcomputers. *Applied Eng. in Agric* . 3(1): 36-41.

Salyani, M., and R. P. Cromwell. 1992. Spray drift from ground and aerial applications. *Trans. ASAE* 35(4): 1113-1120.

Smith, D. B. 1992. Uniformity and recovery of broadcast sprays using fan nozzles. *Trans. ASAE* 35(1): 39-44.

Smith, D. B., F. D. Harris, and C. E. Goering. 1982. Variables affecting drift from ground sprayers. *Trans. ASAE* 25(6): 1499-1503.

Sumner, H. R., C. C. Dowler, P. M. Garvey. 2000. Application of agrichemicals by chemigation, pivot-attached sprayer systems, and conventional sprayers. *Applied Eng. in Agric* . 16(2): 103-107.

USDA-ERS. 1998. Agriculture Outlook. AGO-253, August. Washington, D.C.: USDA Economic Research Service.

Walklate, P. J., G. M. Richardson, J. V. Cross, and R. A. Murray. 2000. Relationship between orchard tree crop structure and performance characteristics of an axial fan sprayer. In *Pesticide Application: Aspects of Applied Biology* 57: 285-292. J. V. Cross, A. J. Gilbert, C. R. Glass, W. A. Taylor, P. J. Walklate, and N. M. Western, eds. Warwick, U.K.: Wellesbourne.

Wolak, F. J. 1989. Pesticide application accuracy survey in South Carolina. *Applied Eng. in Agric* . 5(4): 514-516.

Zhu, H., C. R. Krause, R. D. Fox, R. D. Brazee, R. C. Derksen. 1997. Techniques for assessing spray drift and canopy penetration in nurseries. ASAE Paper No. 975006. St. Joseph, Mich.: ASAE.
